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Directional detection of galactic Dark Matter

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Directional detection of galactic Dark Matter is a promising search strategy for discriminating geniune WIMP events from background ones. We present technical progress on gaseous detectors as well as recent phenomenological studies, allowing the design and construction of competitive experiments.

Direct detection of Dark Matter is entering a new era as several detectors are starting to exclude the expected supersymmetric parameter space[1,2] and new projects of detector are planning to scale-up to ton-scale.[2] An alternative strategy to massive detectors, aiming at high background rejection, is the development of detectors providing an unambiguous positive WIMP signal. This can be achieved by searching for a correlation of the WIMP signal either with the motion of the Earth around the Sun, observed as an annual modulation,[3] or with the direction of the solar motion around the galactic center, observed as a direction dependence of the incoming WIMP flux,[4] towards $(\ell_\odot = 90°, b_\odot = 0°)$, which happens to be roughly in the direction of the Cygnus constellation. The latter strategy is generally referred to as directional detection of Dark Matter and several projects of detector are being developed for this goal.[5–10] Phenomenological studies have shown that not only the forward/backward asymmetry can be used to discriminate Dark Matter and background. By studying the recoil spatial distribution with various statistical methods,[11–13] useful information may be extracted from such measurements. Recently, a statistical tool, using a map-based likelihood analysis, has been developed[14] to extract information from data samples of forthcoming directional detec-
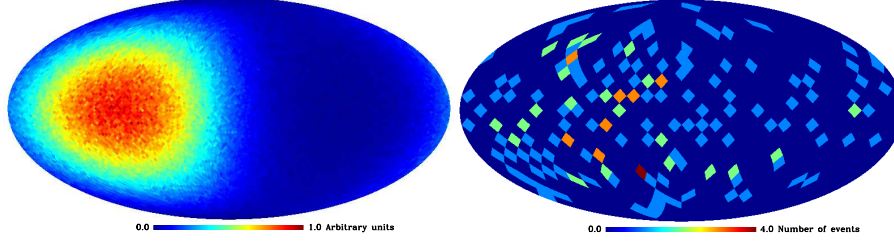
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Fig. 1.   Left panel : WIMP-induced recoil distribution within the framework of an isotropic isothermal spherical Milky Way halo. Right panel : a typical simulated measurement, *i.e.* 100 WIMP-induced recoils and 100 background events with a low angular resolution. Maps are Mollweide equal area projections. Figure from.[14]

tors, thus changing the search strategy from background rejection to Dark Matter identification method.

Figure 1 presents on the right panel a typical simulated recoil distribution observed by a directional detector : 100 WIMP-induced events and 100 background events. For an elastic axial cross-section on nucleon $\sigma_n = 1.5 \times 10^{-3}$ pb and a 100 GeV.c^{-2} WIMP, this corresponds to an exposure of $\sim 7 \times 10^3$ kg.day in ^{3}He and $\sim 1.6 \times 10^3$ kg.day in CF$_4$, on their equivalent energy ranges as discussed in.[14] Low resolution maps are used ($N_{bins} = 768$) to account for low angular resolution. In order to extract information from such a measurement, a blind likelihood analysis has been developed,[14] allowing to retrieve without any prior, both the main direction of the incoming events (ℓ, b) and the number of WIMP events contained in the map. It can be concluded that this simulated map contains a signal pointing towards the Cygnus constellation within $10°$, with $N_{wimp} = 96 \pm 15$ (68%CL), corresponding to a high significance galactic Dark Matter detection. Such a result could be obtained, with a background rate of ~ 0.07 kg^{-1}day^{-1} and a 10 kg CF$_4$ detector operated during ~ 5 months, noticing that the detector should allow 3D track reconstruction, with sense recognition[15,16] down to 5 keV.

Several directional detectors are being developed and/or operated : DM-TPC,[5] NEWAGE,[6] DRIFT,[7] MIMAC.[8] A detailed overview of the status of experimental efforts devoted to directional dark matter detection is presented in.[10] Directional detection of Dark Matter requires track reconstruction of recoiling nuclei down to a few keV. This can be achieved with low pressure gaseous detectors[17] and several gases have been suggested : CF$_4$,^{3}He $+$ C$_4$H$_{10}$ or CS$_2$. For these targets, although their detection characteristics may be different (e.g. track length, drift velocity and straggling), their directional signature can be considered as equivalent.[14] Both the energy and the track of the recoiling nucleus need to be measured precisely. Ideally, recoiling tracks should be 3D reconstructed as the required exposure is decreased by an order of magnitude between 2D read-out and 3D read-out.[13] Sense recognition of the recoil track is also a key issue for directional detection.[15,16]

The MIMAC project is based on a matrix of gaseous μTPC, filled either with one or several gases amongst ^{3}He, CF_4, CH_4 and C_4H_{10}. Using both ^{3}He and CF_4 in a patchy matrix of μTPC opens the possibility to compare the rates for two atomic masses, and to study neutralino interaction separately on neutron and proton. With low mass targets, the challenge is to measure low energy recoils, e.g. below $\mathcal{O}(1-10)$ keV for Helium, by means of ionization measurements. Accurate energy measurement has been achieved with Helium μTPC, implying precise knowledge of the ionization quenching factor down to sub-keV energies.[18] 3D reconstruction of mm tracks is also an experimental challenge. A μTPC prototype with a 16.5 cm drift space has been developed and successfully operated in surface laboratory and tested with mono-energetic neutron fields at the AMANDE facility (IRSN Cadarache).[20] We use a bulk micromegas[21] with a 3×3 cm^2 active area, segmented in 300 μm pixels, and a 325 LPI (Line Per Inch) weaved 25 μm thick stainless steel micro-mesh. The μTPC prototype is equipped with a dedicated front end ASIC (BiCMOS-SiGe 0.35 μm), self-triggered and able to perform a 40 MHz anode sampling.[19] The detection strategy is the following : primary electrons are produced by the recoil nucleus and drifted towards the grid in the drift space and then collected on the pixelized anode. This allows to access information on X and Y coordinates. The Z coordinate is then obtained with a 40 MHz sampling of the anode, providing the electron drift velocity is known. Next step of the MIMAC project is the construction of a small μTPC matrix to be operated in underground laboratory.

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